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ITR-1320(Del.)

JTL 019630

PRELIMINARY REPORT

Operation REDWING

PACIFIC PROVING GROUNDS

May - July 1956

410898

Photostat Price $ [illegible]
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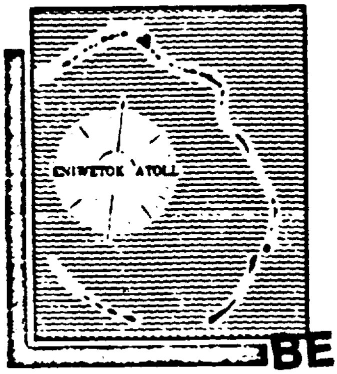
Project 2.66

EARLY CLOUD PENETRATIONS



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HEADQUARTERS FIELD COMMAND. ARMED FORCES SPECIAL WEAPONS PROJECT
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OPERATION REDWING - PRELIMINARY REPORT

PROJECT 2.66

SEPTEMBER 1956

EARLY CLOUD PENETRATIONS

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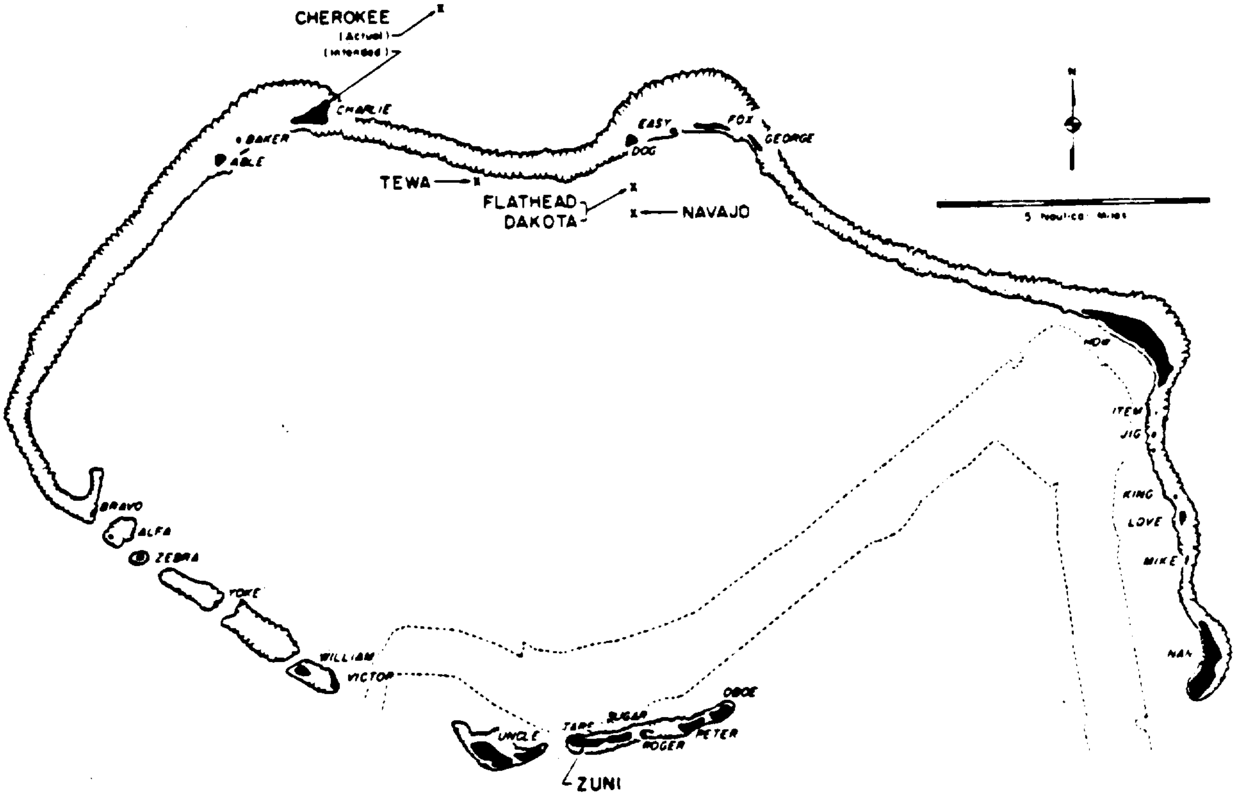
SUMMARY OF SHOT DATA, OPERATION REDWING

Shot Name (Unclassified)	Date (PPG)	Time (Approximate)	Location	Type	H&N Coordinates (Actual Ground Zero)	Geographic ° ' "
Lacrosse	5 May	0629	Eniwetok Yvonne	Surface Land	124515 E 106885 N	11 33 29 162 21 18
Cherokee	21 May	0551	Bikini Off Charlie	Air Drop Over Water	96200 ± 100 E 185100 ± 500 N	11 43 50 165 19 46
Zuni	28 May	0556	Bikini Tare	Surface Land Water	110309 E 100154 N	11 29 48 165 22 09
Yuma	28 May	0756	Eniwetok Sally	200-ft Tower	112155 E 130604 N	11 37 24 162 19 13
Erie	31 May	0615	Eniwetok Yvonne	300-ft Tower	127930 E 102060 N	11 32 41 162 21 52
Seminole	6 June	1255	Eniwetok Irene	Surface Land[a]	75237 E 149897 N	11 40 35 162 13 02
Flathead	12 June	0626	Bikini Off Dog	Barge Water	116768 E 164094 N	11 40 22 165 23 13
Blackfoot	12 June	0626	Eniwetok Yvonne	200-ft Tower	126000 E 104435 N	11 33 04 162 21 33
Kickapoo	14 June	1126	Eniwetok Sally	300-ft Tower	114018 E 132295 N	11 37 41 162 19 32
Osage	16 June	1314	Eniwetok Yvonne	Air Drop Over Land	126647 ± 50 E 102851 ± 50 N	11 32 48 162 21 39
Inca	22 June	0956	Eniwetok Pearl	200-ft Tower	105300 E 133540 N	11 37 53 162 18 04
Dakota	26 June	0606	Bikini Off Dog	Barge Water	116767 E 164097 N	11 40 22 165 23 13
Mohawk	3 July	0606	Eniwetok Ruby	300-ft Tower	109737 E 132165 N	11 37 39 162 18 49
Apache	9 July	0606	Eniwetok Flora	Barge Water	69227 E 148063 N	11 40 17 162 12 01
Navajo	11 July	0556	Bikini Off Dog	Barge Water	116816 E 160604 N	11 39 48 165 23 14
Tewa	21 July	0546	Bikini Charlie-Dog Reef	Barge Water	99776 E 164476 N	11 40 26 165 20 22
Huron	22 July	0616	Eniwetok Flora	Barge Water	70015 E 148304 N	11 40 19 162 12 09

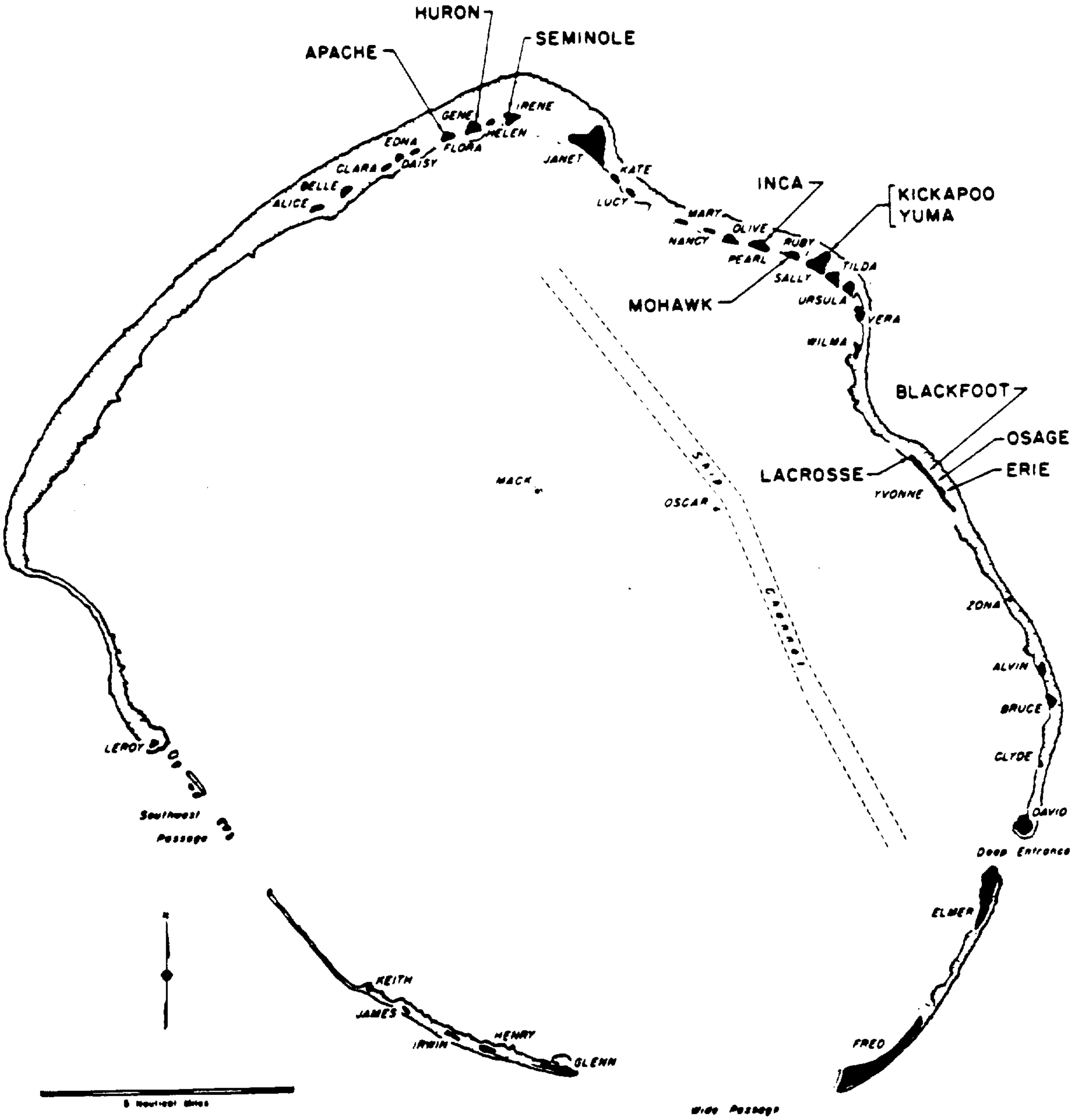
[a] See ITR-1344 for further details.



Airukiiji	Oboe	Bokoaetokutoku	Alfa	Eniirikku	Uncle	Rochikarai	Love
Airukiraru	Peter	Bokobyaadaa	Able	Eninman	Tare	Romurikku	Fox
Aomoen	George	Bokonejien	Baker	Enyu	Nan	Rukoji	Victor
Arriikan	Yoke	Bokonfuaaku	Rem	Ionchebi	Mike	Uorikku	Easy
Bigiren	Roger	Bokororyuru	Bravo	Namu	Charley	Yomyaran	Jig
Bikini	How	Chieerete	William	Ourukaen	Zebra	Yurochi	Dog
		Eniairo	King	Reere	Sugar		

Bikini Atoll. Locations of test detonations during Operation REDWING are indicated by large lettering and arrows. Native island names with corresponding military identifiers are given in the tabulation.

[redacted]



Aaraanbiru	Vera	Chinieero	Alvin	Igurin	Glenn	Ribaion	James
Aitsu	Olive	Chinimi	Clyde	Japtan	David	Rigili	Leroy
Aniyaanii	Bruce	Cochita	Daisy	Kirinian	Lucy	Rojoa	Ursula
Aomon	Sally	Coral Heads	Mack, Oscar	"M"	Zona	Ruchi	Clara
Biijiri	Tilda	Eberiru	Ruby	Mui	Henry	Rujoru	Pearl
Bogairikk	Helen	Elugelab	Flora	Muzin	Kate	Runit	Yvonne
Bogallua	Alice	Engebi	Janet	Parry	Elmer	Sandildefonso	Edna
Bogombogo	Belle	Eniwetok	Fred	Piiraai	Wilma	Teiteiripucchi	Gene
Bogon	Irene	Girinien	Keith	Pokon	Irwin	Yeiri	Nancy
Bokonaarappu	Mary						

Eniwetok Atoll. Locations of test detonations during Operation REDWING are indicated by large lettering and arrows. Native island names with corresponding military identifiers are given in the tabulation.

[redacted]

DEDICATION

This report is dedicated to Paul Marcus Crumley, Captain, United States Air Force, who gave his life on the 18th day of May, 1956 in the prosecution of this work. He did much of the work of assembling the material and planning all the details necessary to the proper conduct of the project. May this report and the value of this work stand as a small evidence that he did not die in vain.

[redacted]

ABSTRACT

Twenty-seven penetrations of [redacted] clouds from multimegaton-range detonations were made at times ranging from 20 to 78 minutes after detonation and at altitudes ranging from 20,000 to 50,000 feet. Sixteen of these penetrations were earlier than 45 minutes and seven were earlier than 30 minutes.

Maximum radiation dose rates as high as 800 r/hr were encountered, and several flights yielded total radiation doses to the crew of 15 r, as measured by film badges, and 35 to 40 r, as measured by instrumentation more sensitive to low-energy radiation.

It was found that the average radiation dose rate in the mushroom of the cloud from a 100-percent-fission-yield detonation would be:

$$\bar{D} = 1.0 \times 10^5 t^{-1.7}$$

Where: $\bar{D}$ = Average dose rate, r/hr.
t = Time after detonation, minutes.

This relationship holds for times from 3 to 80 minutes after detonation.

The average dose rate in the stem of the cloud from water-surface bursts was found to be less than the dose rate in the mushroom by a factor of from five to ten. The radiation dose rate in the cloud is independent of yield, but is proportional to the ratio of fission yield to total yield.

In a high tropopause area, a flight through a cloud from a 100-percent-fission-yield multimegaton-range weapon in a high-performance aircraft may be made at 45,000 feet at a time of 20 minutes after detonation. The average mission dose of this flight would be 25 r. At 30,000 feet, a penetration of the stem of the cloud may be made as early as 10 minutes after detonation with a radiation dose of the same magnitude.

The dosage received on the return to base flight due to contamination on the aircraft (B-57B) was found to be about 15 percent of the total mission dose for flights lasting about 50 minutes after the cloud penetration.

ACKNOWLEDGMENTS

The authors wish to acknowledge the assistance of a large number of persons who contributed to the success of Project 2.66.

The following members of the Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico, contributed materially to the execution of general or specific parts of the project: Major J. L. Dick and M/Sgt J. M. Pulliam who assisted in the film measurements of total dose and of contamination on the aircraft, and Capt R. F. Merian, 1/Lt M. V. Harlow, Jr., 1/Lt D. L. Endsley, 2/Lt R. L. Capener, and M/Sgt W. P. Schaus, Sr., who contributed to the development, maintenance, and repeated calibration of the electronic instruments. The same individuals installed these instruments in the aircraft prior to each shot and read out the data after each shot. Lt Col L. A. Kiley and 1/Lt W. C. Jones rendered excellent rear-echelon logistic support to the project.

Mr. G. E. Koch aided the project materially by providing technical advice on the electronic instrumentation at the test site.

The project is indebted to the Tactical Air Command for the assignment of the aircraft and the selection of exceptionally fine officers and maintenance personnel to support the flight requirements of the project. The officers and men of the flight element, under command of Lt Col W. B. Furman, performed an outstanding job of maintaining and flying these aircraft. The project officers are grateful to these officers and men for their contributions to the success of the flights and, hence, the success attained by the project.

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TABLES

FIGURES

CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of this project was to measure the radiation dose and dose rate one would experience in flying through the cloud resulting from a megaton-range weapon and some factors affecting personnel safety in the event of an operational situation requiring flights through such clouds.

Specific information was sought on the radiation dose rates inside the cloud, the total dose received in flying through such a cloud, the total dose received on the return flight after flying through the cloud, and the conditions of flight inside the cloud.

This information is needed by the operational commands of the Air Force in their planning to insure the most-effective utilization, consistent with crew safety, of aircraft in cloud areas.

1.2 BACKGROUND AND THEORY

During Operation GREENHOUSE the first significant data on gamma dose rates within atomic clouds were collected. These are reported in Reference 1. The data were collected by drone aircraft flown through the clouds from weapons ranging in yield and at times of from 3 to 25 minutes after detonation. Reference 1 shows average gamma dose rates within the cloud to be of the orders of 10^4 r/hr from 3 to 5 minutes after detonation and 350 r/hr at 20 minutes after detonation.

Further measurements of gamma dose rates within atomic clouds were made in Operation UPSHOT-KNOTHOLE and reported in Reference 2. Dose-rate-measuring instruments were mounted in parachute-borne canisters, and the dose-rate instruments previously used by the Naval Radiological Defense Laboratory (NRDL) in Operation GREENHOUSE (Reference 1) were mounted in QF-80 drone aircraft. Both the canisters and the QF-80's passed through only the head, or mushroom, of the clouds resulting from weapons ranging in size. Dose rates of the order of 10^4 r/hr were measured from 2 to 6 minutes after detonation.

A compilation of the GREENHOUSE and UPSHOT-KNOTHOLE average dose rates as a function of time after detonation is presented graphically in Reference 2. These points are also included in Figure 3.2 of this report. The time after detonation for each point is the approximate time after detonation at which the airplane or canister entered the cloud. A least-square analysis of the data showed that the best-fit line had the equation:

$$\bar{D} = 1.31 \times 10^5 t^{-2.06} \qquad (1.1)$$

Where: $\bar{D}$ = Average dose rate, r/hr.
t = Time after detonation, minutes.

Consideration of Reference 2 led to the following generalizations which were used as guides in the initial planning of this project: (1) The dose rate in the cloud is relatively independent of yield. (2) Within a factor of two, the average dose rate in a cloud is given by Equation 1.1.

The first manned penetrations at early times after detonation (17 to 41 minutes) were made during Operation TEAPOT. These penetrations were made through clouds from weapons ranging in yield. The average dose rate in the cloud as measured during these penetrations is shown graphically in Figure 3.2.

The gamma radiation dose rate within the atomic cloud resulting from kiloton-range weapons has received theoretical consideration in References 3, 4, 5, 6, and 7. The outstanding features of many of these calculations are the very-high gamma dose rates predicted for very-early times due to small cloud size and high fission-product concentration.

CHAPTER 2

PROCEDURE

2.1 OPERATION

Five B-57B aircraft which were instrumented to measure gamma radiation dose rate, integrated dose, and conditions of flight were flown through the clouds resulting from the detonation [redacted] ranging in yield.

On the day prior to a shot, all of the instrumentation was checked for proper operation, installed in the aircraft, and readied for use. The flight crews were briefed on the desired flight pattern, altitudes and times of penetrations, and forecast development characteristics of the cloud. These characteristics included size, stabilization levels, and drift.

All aircraft took off at predetermined times in order to permit proper positioning at shot time. After the shot was fired, the cloud was surveyed visually by the director in the lead aircraft. Positions and times of penetration were then finalized. Penetrations were made at intervals of from 4 to 10 minutes and at varying altitudes. This time spacing permitted some of the results of the first penetrations to be used in planning the succeeding penetrations.

Two types of maneuver were utilized in the penetration phase. In both cases the cloud was approached in straight and level flight. After entering the visible cloud, the pilot either executed a standard 180-degree turn and made his exit or continued on a straight course through the cloud. The type of maneuver to be employed was decided prior to the penetration run. However, the aircrews were briefed on emergency procedures which permitted changing from the straight-through to the 180-degree-turn maneuver at their discretion if excessively high dose rates were encountered. A dose rate two times greater than the predicted dose rate was considered excessive. Upon exit from the cloud, the aircraft returned to base and the records were removed immediately for analysis.

2.2 INSTRUMENTATION

The following instruments and devices were used to obtain data for this project: (1) KAEC Model M1432 automatic-recording radiation-rate meter (P-Meter); (2) Bioscel (IM-111 (XE-1)/UD) radiation-rate meter; (3) Sigmatron radiation-integrating dosimeter; (4) quartz-fiber dosimeters (Bendix Models 619 and 622) radiation integrating dosimeter; (5) National Bureau of Standards (NBS) film packs radiation-integrating dosimeter; (6) Rad-Safe personnel film badge, radiation-integrating dosimeter; (7) AN/PDR-39 (T1B) radiation-rate meter; (8) intervalometer; and (9) photopanel.

The last two are not radiac devices, but are included in this section for convenience of presentation. A description of each device is given below. All radiation-measuring devices were calibrated at NBS prior to the Operation. They were recalibrated intermittently at the test site using a Co^{60} source.

2.2.1 KAEC Model M1432 Automatic-Recording Radiation-Rate Meter (P-Meter). The P-Meter was designed and built by the West Coast Electronics Laboratory of the Kaiser Aircraft and Electronics Corporation at Palo Alto, California, under contract with and according to specifications furnished by Air Force Special Weapons Center (AFSWC). Seven complete assemblies were procured. The equipment consisted of three airborne components (probe, power supply, and compressor-amplifier-recorder unit) and one nonairborne component (playback unit). A block diagram showing the relationship of these units constitutes Figure 2.1.

The entire airborne assembly was mounted in the nose section of a B-57B. The instruments were operated by the 28-volt aircraft power supply. The wire recorder could be started manually at any time during the flight by means of a switch in the pilot's compartment. It could also be started automatically by use of the intervalometer setting. Once turned on, it continued to record until the recording wire was completely used (about 2 1/2 hours) or until the power was turned off.

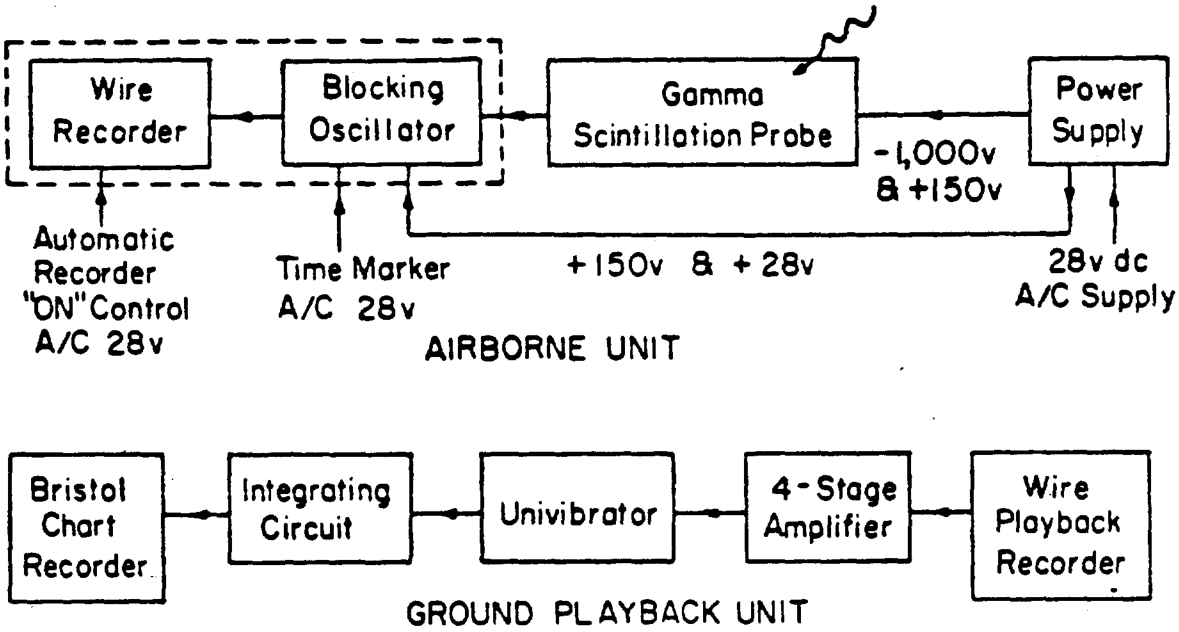

Figure 2.1 Block diagram of automatic recording radiation rate meter (P-Meter).

The probe was the sensing element and consisted of a Scintilon (trade name used by National Radiac Company) sphere, DuMont 6292 photo-multiplier tube, and a regulated voltage divider with temperature compensation. This was housed in a 2 1/2-inch diameter aluminum tube having a wall thickness of 1/16 inch with an added 0.01 inch of tin outside the hemispherical end that covered the Scintilon. The inside of this hemisphere was coated with zinc sulfide in order to enhance low-energy response so that satisfactory performance was obtained from 80 kev up to 1.3 Mev.

The compressor-amplifier-recorder unit received current from (i.e., supplied electrons to) the probe. The intensity of this current varied linearly with the dose rate. This current is supplied by a cathode-biased low-mu triode (CK6152) and results in a logarithmic variation of the plate voltage of this tube. This plate voltage is connected to the grid of a blocking oscillator (CK5703WA) through a high resistance. The frequency of the blocking oscillator is thus made to vary as the logarithm of the dose rate, and after amplification through another CK5703WA, the output is impressed on the recording head of the wire recorder.

The power supply consisted of six 26A7-GT tubes connected in parallel so as to oscillate at about 1,000 cps when fed 28 volts from the aircraft power supply. The output of the tubes is stepped up, rectified, and regulated to result in +150 volts for B+ voltage in the compressor-amplifier-recorder and -1,000 volts for the photomultiplier tube in the probe.

The playback unit consisted of a playback recorder of the same type as was used for taking data during penetrations. The frequency-modulated output of the playback unit was amplified, pulse-shaped, and integrated. This integrated, slowly varying direct current was then applied to the input of a standard 12-inch-strip chart recorder (Bristol Model 1892). A logarithmic presentation of dose rates from 1 r/hr to 5,000 r/hr was given on the chart. Calibration tests at NBS using Co^{60} have indicated an overall read-out accuracy of ± 20 percent over the range from 1 r/hr to 2,000 r/hr.

2.2.2 Bioscel Radiation-Rate Meter. The Bioscel was designed and built by the Evans Signal Laboratory of the U. S. Army Signal Corps in accordance with specifications furnished by the Air Force Special Weapons Center (AFSWC). Type designation IM-111 (XE-1)/UD was obtained through Army channels. Twenty of these units were procured. Two complete Bioscels were installed in each aircraft with the sensing elements located directly behind the pilot's seat. Data obtained with one instrument were recorded by photographing a remote meter mounted in the photopanel. The remote meter from the second instrument was placed in the pilot's compartment, above and to the right of the instrument panel. As shown in Figure 2.2, the instrument consisted of an ion chamber, an amplifier, a control panel, a battery container, and an indicating meter which presented rates from 1 r/hr to 2,000 r/hr. All of these components, except the meter and its cabling, were contained in a cylindrical aluminum housing 3 inches in diameter and 10 inches in length which had a flange at the control panel for mounting.

The ion chamber and amplifier were potted together in the ion-chamber-assembly module. The potting compound was an epoxy resin, which gave an hermetically sealed unit. The unit passed tests for leakage at -55°F and 0.1 psi. The ion-chamber volume was 85 cm^3. The applied sweep-out voltage was approximately 7 volts. This resulted in nonsaturated operation and produced a roughly logarithmic indication on the meter. Calibration was obtained by varying this voltage between 6.3 and 8.8 volts. Zero adjustment was made before use (or calibration) by adjustment of coarse and fine rheostats in the cathode circuit, through which resistances a voltage drop was obtained to actuate the meter.

[redacted]

The battery box is a separate module from the ion chamber assembly module and was located in the end of the tubular aluminum housing farthest from the control panel. It contained three BA-1318/U and one 1328/U batteries. These were sufficient to furnish continuous operation for 200 hours.

2.2.3 Sigmatron Radiation Integrating Dosimeter. The Sigmatron was built by the Research Directorate of AFSWC, Kirtland Air Force Base (KAFB), and was based on a similar design used by Los Alamos Scientific Laboratory (LASL) for a much-lower-range instrument, called the "Integron." Eighteen of these units were built. The ion chamber which was used was designed and built by NRDL to meet specifications prepared by AFSWC. The information furnished by the instrument is total gamma dosage, with two ranges (25 r and 100 r full scale) available by changing an internal connection. Two Sigmatrons were used in each airplane, mounted just behind the pilot, with a remote meter for each. One meter was in the photopanel and the other was in the pilot's compartment. The first prototype of this instrument tested at NBS integrated total dosage with an accuracy of ± 20 percent at energies higher than about 125 kev. At 80 kev the loss in response was only about 25 percent. Accuracy was independent of rate up to 2,000 r/hr.

A block diagram of the Sigmatron is shown in Figure 2.3. The instrument operated as follows: The ion chamber had a sensitivity of 1.1

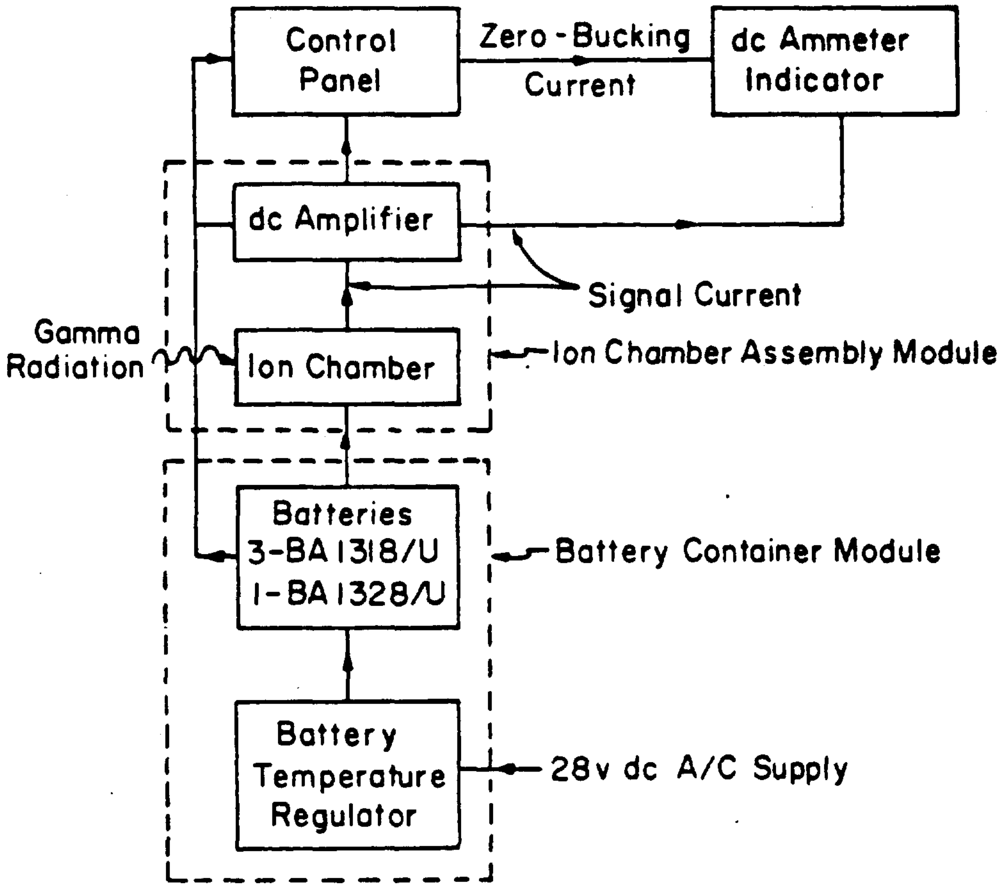

Figure 2.2 Block diagram of Bioscel radiation-rate meter.

[redacted]

$x\ 10^{-8}$ amp/r/hr and insulation of more than 10^{13} ohms. The integrating capacitors (0.3 and 1.3 microfarads) had a time constant of more than 3 days. These capacitors were in the electrometer circuit. The ion-chamber current charged whichever capacitor was in use so as to reduce the grid potential of a CK5886 electrometer tube and, hence, increase the positive plate voltage of a CK526AX amplifier tube. This increased plate voltage resulted in an increased cathode current in this tube. This increased cathode current raised the cathode potential and caused a current to flow in the microammeter loop. It also resulted in negative feedback in the input to the CK5886, since it tended to cancel out the voltage produced by charging the integrating capacitors. The negative feedback had the beneficial action of effectively multiplying the capacity of the capicators without increasing the leakage; hence, the dynamic range of the instrument was extended without exceeding the straight-line portion of the I_p versus I_g characteristic curve of the CK5886.

The three instruments just discussed (P-Meter, Bioscel, and Sigmatron) all have a response time of less than 1 second for 100 percent response.

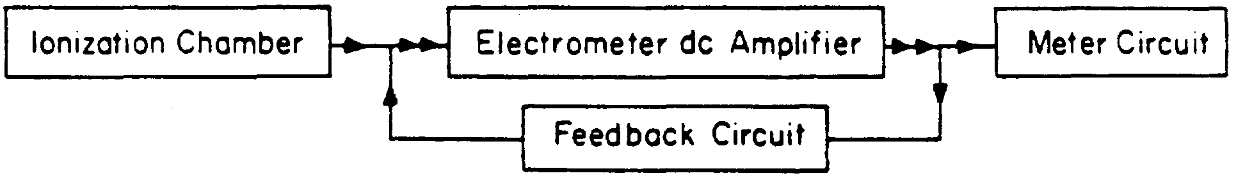

Figure 2.3 Block diagram of Sigmatron radiation-integrating dosimeter.

2.2.4 Other Dosimeters. The integrated gamma radiation dose during cloud passage and on the return flight was measured by a number of standard integrating dosimeters. Each crew member carried pencil-type dosimeters and a Rad-Safe film badge. Quartz-fiber dosimeters were mounted in the cockpit to record the total dose received on the mission. The NBS packs were placed in both the pilot's and observer's compartments. The NBS film packs were also mounted in the nose compartment for comparison of the total dose received in the nose with that received in the cockpit. This latter comparison was necessary, because the P-Meter was mounted in the nose compartment while the sensing elements of all other instruments were in the cockpit.

The AN/PDR-39 (T1B) is a standard Air Force gamma rate meter and was used to follow the decay rate in the pilot's and observer's positions after completion of the flight. This study continued for 12 hours. Information concerning this instrument can be obtained through Air Force supply channels.

2.2.5 Intervalometer. The intervalometer, as its name implies, was a device used to actuate the camera in the photopanel at selectable intervals. It was designed and built by the 4925th Test Group (Atomic) at KAFB. One of these instruments, along with the associated photopanel

[redacted]

control box was mounted in each airplane. The intervalometer was placed in the nose compartment, and the control box was located to the right of the pilot.

The actuating signals to the camera were fed through microswitches actuated by two separate cams driven by a common motor. This arrangement provided two speeds, "fast" (approximately 3 signals per second) and "slow" (approximately 3 signals per minute). Either could be selected manually by the pilot by means of a switch on the control box. Two camera speeds were required in order to economize on film, yet obtain rapid photographs in the radiation cloud. In addition, there was a third position marked "auto" which automatically changed the speed from "slow" to "fast" when the ambient radiation exceeded a given level, usually set between 1 and 10 r/hr. This part of the circuit is described in the next paragraph.

A dynamotor driven by the airplane's 28-volt power supply provided +150 volts dc, which was converted to -700 volts dc by means of a multivibrator, amplifier, and filter. This -700 volts was connected to ground through an Anton 5980/BS-2 Geiger-Muller tube and a 1.2-megohm resistor. A 0.0001-microfarad condenser connected the junction of these two elements to the grid of a CK5814 tube and, in conjunction with the resistor, determined the quench of the Geiger-Muller tube. As the radiation field increased, the Geiger-Muller tube broke down more often, sending negative pulses through the condenser to a CK5814 tube. These pulses were amplified and inverted in a subsequent stage and were fed through the coil of a relay. When the repetition rate became sufficiently great (at a rate somewhat lower than the maximum allowed by the quench circuit), the direct-current component of the pulses became sufficient to close the relay, which in turn closed a second relay which switched the interval control from "slow" to "fast." When the radiation rate diminished sufficiently, the interval control reverted to "slow" automatically.

2.2.6 Photopanel. The camera and photopanel located in the nose of the aircraft were used to photograph the meters from the Sigmatron and Bioscel, whose sensing elements were located in the cockpit. Also installed in the photopanel were a clock, altimeter, accelerometer, and airspeed indicator. When correlated with the radiac instrument readings, these gave a record of time in cloud, altitude of penetration, and conditions of flight within the cloud. The photopanel also contained a small marker light. This was controlled by a toggle switch on the photopanel control box. Using this light the pilot could mark the film at specific times, such as cloud entry and exit.

The camera used was a Vought 16-mm recording camera loaded with 100 feet of Eastman Special Emulsion (SO 1112) film. This film is not fogged by gamma doses of less than 500 r. Suitable lighting was included to provide the intense light required for this special film. The lights and the camera utilized the aircraft's 28-volt power supply.

2.3 DESCRIPTION OF REQUIRED DATA

In order to satisfy the purposes of this project, accurate information was required on the following parameters: (1) time of penetration

[redacted]

of the radioactive cloud; (2) total radiation dose on the flight; (3) radiation dose accumulated in transit of the radioactive cloud; (4) length of time required to fly through the cloud; (5) radiation dose accumulated on the flight back to base due to contamination on the aircraft; (6) maximum dose rate in the radioactive cloud; (7) dose rate in the crew compartment immediately after exit from the cloud due to contamination on the aircraft; (8) the rate of decay of this contamination; and (9) conditions of flight inside the radioactive cloud, i.e., turbulence and icing.

All of these data, except the last, were recorded automatically with the instrumentation described in Section 2.2. The items of information desired from each flight and the instruments which were used to provide them are summarized in Table 2.1 Most of the information was available directly from the installed instrumentation, while some additional information was obtained by indirect methods as indicated in Sections 2.3.1 through 2.3.9. It should be noted that these indirect methods constituted, in every case, a duplicate method for obtaining a check on the same data obtained by one or more direct measurements.

In addition, the pilot (and observer when present) made observations during the flight on the following parameters: (1) dimensions of the cloud at various altitudes prior to penetration; (2) time and altitude of penetration; (3) type of penetration; (4) length of time in the radioactive cloud; (5) maximum dose rate in the cloud; (6) dose rate in the cockpit on exit from the cloud due to contamination on the aircraft; (7) accumulated dose in the cockpit at time of exit from the cloud; and (8) degree of turbulence and icing noted during passage through the radioactive cloud.

These observations were reported to the flight director in the air and were transcribed from the pilot's and director's notes during the post-flight debriefing. These observations by the pilot duplicate information recorded automatically by the instrumentation in the aircraft in all cases except icing conditions in the cloud.

2.3.1 Total Radiation Dose. The total radiation dose was measured directly by the Sigmatrons, quartz-fiber dosimeters, NBS film packs, and Rad-Safe film badges. It was also obtained by integrating the area under the dose-rate-versus-time curves yielded by the P-Meter and the Bioscel mounted in the photopanel.

2.3.2 Length of Time in Cloud. The pilot flashed the marker light on the photopanel at the times which he considered to be his entry and exit from the cloud. Time in the visible cloud was then computed by observation of the clock in the photopanel pictures. Time in the radiation cloud was obtained from the P-Meter and Bioscel data. These two instruments provided curves of dose rate as a function of time. For purposes of this calculation, the entry and exit were considered to be those times at which the dose rate was 5 percent of the maximum rate observed.

2.3.3 Radiation Dose in Cloud. The radiation dose received in the cloud was measured by integration of the area under the P-Meter and Bioscel curves between cloud entry and cloud exit. The Sigmatron in the

[redacted]

photopanel also gave a direct indication of dose in the cloud. It required only that the meter be observed in the film frames where the marker light occurred.

The NBC film packs gave an indirect measure of the dose in the cloud. This was computed by subtracting the return flight dose which was calculated from the T1B decay-rate measurements from the total dose indicated by the film packs.

2.3.4 Dose on Return Flight. The radiation dose on the return flight was measured directly by the P-Meter, Bioscel, and Sigmatron. In each instance all that was necessary was to subtract the dose in the cloud from the total dose. The difference was the dose received on the return flight.

TABLE 2.1 SUMMARY OF SOURCES OF REQUIRED DATA

Data directly available is indicated by x;
indirectly available is indicated by 0.

Information Desired on Each Flight	P-Meter	Bioscel	Sigmatron	Quartz-fiber Dosimeters	NBS Film Packs	Rad-Safe Film Badge	T1B
Total Radiation Dose	x	x	x	x	x	x	
Time in Cloud	x	x					
Dose in Cloud	x	x	x		0		
Dose on Return Flight	x	x	x				0
Maximum Dose Rate in Cloud	x	x					
Average Dose Rate in Cloud	x	x	x		0		
Dose Rate at Cloud Exit	x	x					0
Decay Rate on Return Flight	x						0
Contamination Factor	x				0		0

An indirect method of obtaining that portion of the radiation dose received after exit from the cloud and during the return flight was by extrapolation of the decay-rate curve measured by the T1B after the aircraft was on the ground back to cloud-exit time and integration of the area under the curve from cloud-exit time to time of landing.

2.3.5 Maximum Dose Rate in Cloud. The maximum dose rate in the cloud was taken directly from the P-Meter and Bioscel curves. The pilot also observed the maximum dose rate indicated by the Bioscel meter in the cockpit.

2.3.6 Average Dose Rate in Cloud. The average dose rate in the cloud was calculated by dividing the dose received in the cloud by the time in the cloud. Both of these were provided directly by the P-Meter,

[redacted]

Bioscel, and Sigmatron. Since the dose in the cloud was obtained indirectly from the NBS film packs, these are also an indirect source for the average dose rate in the cloud.

2.3.7 Dose Rate at Cloud Exit. The dose rate at cloud exit due to contamination on the aircraft was taken directly from the P-Meter and Bioscel curves. It was also derived by extrapolation of the decay-rate curve from the T1B decay measurements.

2.3.8 Decay Rate on Return Flight. The decay rate of the contamination during the return flight was obtained directly from the P-Meter curves. It was also obtained by extrapolation of the decay rate curve from the T1B measurements.

2.3.9 Contamination Factor. The contamination factor is expressed in percent per minute in the cloud and is defined as:

$$\frac{\text{Dose rate in cockpit at cloud exit}}{(\text{Average dose rate in cloud})(\text{Minutes in cloud})} \times 100 \qquad (2.1)$$

It is a measure of the degree to which this type of aircraft (B-57B) becomes contaminated by flight through the cloud as reflected by the radiation dose rate in the crew compartment after exit from the cloud. It is significant in predicting that portion of the total dose which is derived from contamination on the aircraft during the flight back to base. It is calculated directly from data recorded by the P-Meter.

The contamination factor was computed also using the dose rate at cloud exit as derived from T1B measurements and the average dose rate in the cloud indicated by the NBS film packs.

2.4 MASTER DATA SHEET

The large mass of data was summarized on a master data sheet. One of these sheets was filled out for each penetration flight. A typical sheet is shown in Appendix A.

Some additional data on radiation dose rates in the cloud at times later than 1 hour after detonation were obtained through the courtesy of the Test Aircraft Unit. These data were collected during the cloud-sampling operations of this unit.

CHAPTER 3

RESULTS AND DISCUSSION

Twenty-seven penetrations were made through the clouds resulting from the detonation [redacted] ranging in total yield. These penetrations were made at times of from 20 to 78 minutes after detonation. The indicated altitudes of penetration varied generally from 30,000 feet to 50,000 feet, with one penetration being made at 20,000 feet. Penetrations were made through clouds from land-surface, water-surface, and air detonations.

Maximum dose rates as high as 800 r/hr were encountered in some of the early penetrations, and several flights yielded total radiation doses to the crew of 15 r, as measured by film badges, and 35 to 40 r, as measured by instrumentation more sensitive to soft gamma radiation than the film dosimeters. On other flights, the whole-body radiation dose as measured by Rad-Safe film badges was as low as 100 mr. The dosage authorized by the Surgeon General of the Air Force and the Commander of Joint Task Force Seven for the aircrews on this project was 50 r, with a limiting planning dosage of 25 r for any single penetration. No penetrations were made in which the maximum dose to be expected, as measured by Rad-Safe film badges, would exceed 25 r.

The experimental plan proved to be satisfactory, and data to satisfy the objectives of this project were obtained. The data are presented in Table 3.1 The sections which follow discuss the results as they appear in the table.

3.1 TIME AND ALTITUDE OF PENETRATION

The times of penetration varied as indicated above. The first penetration on each shot was through the stem of the cloud. Succeeding penetrations were at higher altitudes through the intermediate zone between the stem and mushroom or through the mushroom. All penetrations below 40,000 feet were considered to be penetrations of the stem. Penetrations between 40,000 and 45,000 feet were intermediary between the stem and mushroom. Penetrations above 45,000 feet were in general through the mushroom of the cloud.

3.2 LENGTH OF TIME IN THE RADIOACTIVE CLOUD

The length of time in the cloud recorded in Table 3.1 represents the period of time from the moment the radiation intensity reached a value of 5 percent of the maximum intensity noted in the cloud until the intensity subsequently diminished to this 5 percent value. In penetrations of the stem or mushroom, this time corresponds closely to the time in the visible cloud reported by the pilot. However, in penetrations just below the altitude of the mushroom, the length of time in the radiation field was usually longer than that in the visible cloud by a factor comparable to the time the plane was beneath the overhanging mushroom but was not in the visible cloud. The length of time in the radiation field is used in Table 3.1, since the dimensions of the radiation field are of greater interest in this report than the dimensions of the visible cloud. The time required to pass through the radiation cloud varied from 1 minute for stem penetrations to about 5 minutes for the mushroom penetrations of the clouds from the higher-yield detonations. More-detailed information on cloud size as a function of time after detonation, yield of detonation, and altitude are presented in a later section of this report.

3.3 RADIATION DOSE RATES IN THE CLOUD

The maximum and average radiation dose rates recorded for each penetration by the various instruments previously described are given in Table 3.1. The maximum dose rate recorded on each flight through the cloud was about twice the average dose rate recorded for the total period in the cloud by the same instrument. The average dose rates in the cloud recorded by the P-Meter and Bioscel were generally 100 percent and 15 percent, respectively, higher than that determined by film dosimetry. This is due to the sensitivity of this electronic instrumentation to low-energy gamma radiation to which the film is only minimally responsive. Since film dosimetry is more widely accepted as an indicator of whole-body radiation dosage, the film data were used to give dose rates or dosages in all figures and tables presented in this report, unless otherwise specified.

A further study will be made to determine the exact response of the various instruments to various energies of gamma radiation in comparison to the response of the film to the same energies. Detailed results of this study will be included in the final (WT) report for this project,

Appendix B shows a typical plot of the dose rates in the cloud recorded by the P-Meter and Bioscel, together with data which were extracted therefrom for presentation in Table 3.1.

The radiation dose rates observed in the cloud were a function of three primary factors: (1) the nature of the yield of the detonation, i.e., the ratio of the fission yield to the total yield; (2) the altitude at which the penetration is made with respect to the position or height of the mushroom; and (3) the length of time after detonation at which the penetration is made.

<u>3.3.1 Radiation Dose Rates in the Cloud versus Nature of the Yield.</u> Since fission yield is the primary contributor to radioactivity prevailing in the cloud, it is to be expected that the dose rates noted in the cloud would be proportional to the ratio of the fission yield to the total yield. Thus, if two separate detonations of essentially the

3.4 RADIATION DOSES

The total gamma-radiation dose received on a penetration flight can be broken down into two parts: the dose received in the cloud and the dose received on the return flight. The return flight dose for the B-57B was found to be approximately 15 percent of the total dose when the return flight was of about 50 minutes duration. Section 2.3 of this report explains the various direct and indirect methods used to measure the dosage received by the crew, both in the cloud and on the return flight. Data collected by these various methods is presented in TABLE 3.1.

The maximum total dose received by any crew member during a penetration flight associated with this project was approximately 16 r, as measured by film dosimetry. Doses as high as 40 r were recorded by instruments more sensitive to soft gamma radiation than film dosimetry. It is significant to note that the highest radiation doses received do not correspond to the earliest penetrations. The dose received in the cloud is a function of the average dose rate in the cloud and the time spent in the cloud. For each shot the first penetration usually was made at the lowest altitude, and succeeding penetrations were made at higher altitudes.

This plan was followed so that in the event turbulence was encountered, it could be tolerated better at the lower altitude. Thus the earliest penetrations were made through the stem of the cloud. Since the dose rate in the stem was lower than the dose rate in the mushroom at the same time after detonation and since the diameter of the stem was a third to a half of that of the mushroom, lower dosages were received by the crews who made the earlier penetrations of the stem of the cloud than by those crews who made later penetrations of the mushroom. This was true for all shots.

3.6 CONTAMINATION FACTOR

The contamination factor was defined and discussed in Section 2.3.9. Values given in Table 3.1 are from computations made using each of the methods of calculations which were described. The average contamination factor for B-57B aircraft is 0.6 ± 0.2 percent per minute. Both methods of calculation gave about the same value. With a contamination factor of this magnitude, a return to base flight of several hours duration after an early penetration of a radioactive cloud would result in a radiation dose to the crew, during the return flight, of about 25 percent of the total dose.

The contamination factor for any particular type of aircraft is a function of the distance between the crew compartment and the residual contamination on the aircraft. In general, the engines are the most-highly contaminated portion of the aircraft after flight through a radioactive cloud. Project 2.8 of Operation TEAPOT measured contamination factors on several different types of aircraft and concluded the contamination factor to be higher for those aircraft where the crew compartment was close to the engine or engines.

3.9 EFFECTIVENESS OF INSTRUMENTATION

Not all of the instrumentation installed in the aircraft operated satisfactorily on every flight. However, in no case did an aircraft penetrate the cloud without sufficient instrumentation functioning properly to provide the necessary data to satisfy the objectives of this project. Film methods were 100 percent successful in measuring the total dose received by the aircrew on the mission. The photopanel functioned on every penetration, with good pictures resulting from each instrument. On one penetration the pilot set the camera speed on the "slow" position, resulting in one picture every 20 seconds while in the cloud, instead of the desired rate of three pictures per second.

The automatic recording instruments were designed to measure radiation rates up to 2,000 r/hr. On penetrations where the dose rates were quite low, continuous data were not obtained on the return flight. In these cases the total mission dose was always less than 2 r. The P-Meter failed to function on only two of the flights. Thus satisfactory operation of this instrument was obtained in more than 90 percent of the flights. On the two occasions where the P-Meter failed to function, the fault was in the method of installation and not in the instrument itself.

Some trouble was experienced with the Bioscel and Sigmatron. Both of these instruments were battery powered. Even with frequent checks of the battery voltages, satisfactory performance was obtained only about 75 percent of the time. Zero drift was especially troublesome in the Bioscel, leading to poor results at low dose rates. The Sigmatron was designed to measure up to 25 r on the low range. Total dosages smaller than 1 r were not reliably indicated by this instrument.

Film measurements were considered to be accurate to ± 10 percent. Measurements made with the T1B were considered accurate to ± 10 percent. The P-Meter, Bioscel, and Sigmatron were considered to give an accuracy of ± 20 percent. As mentioned in Section 3.3, the P-Meter gave readings about a factor of two higher than film devices. Greater sensitivity and response of the P-Meter to gamma radiation of low energies appears to be the reason for this discrepancy. On the average, the Bioscel and Sigmatron read 15 percent and 25 percent higher respectively than did the film dosimeters.

The flight instruments installed in the photopanel functioned properly on each flight. Indicated altitudes were considered to be correct to ± 500 feet. Times of penetration were accurate to the nearest minute.

The accelerometer installed in the photopanel was not considered to be reliable in giving indications of turbulence in flight. The maximum and minimum needles vibrated to the limit of their movement on takeoff. Photographic records were available of the meter fluctuations within the cloud but could not be correlated with the verbal reports of the pilots concerning conditions of flight within the cloud.

[redacted]

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Twenty-seven penetrations of [redacted] clouds from multimegaton-yield detonations were made at times ranging from 20 to 78 minutes after detonation and at altitudes ranging from 20,000 to 50,000 feet. Sixteen of these penetrations were earlier than 45 minutes after detonation, and seven were earlier than 30 minutes. All penetrations made earlier than 45 minutes were bore-throughs in which the aircraft completely traversed the cloud from one side to the other at the penetrating altitude. Penetrations were made through clouds from air, land-surface, and water-surface detonations. Maximum dose rates as high as 800 r/hr were encountered in some of the early penetrations, and several flights yielded total radiation doses to the crew of 15 r (measured by film badges) and 35 to 40 r (measured by instrumentation more sensitive to soft radiation).

Data collected on these flights and in conjunction with past studies of conditions prevailing within clouds from nuclear detonations warrant a number of conclusions regarding the feasibility of flying through such clouds at relatively early times after detonation:

The average and maximum external gamma-radiation dose rates in the mushroom of the cloud from nuclear detonations are dependent on the penetration time and the fission-to-total-yield ratio of the detonation and are independent of the yield of the detonation. The average radiation dose rate in the mushroom of the cloud from a 100-percent-fission-yield detonation as a function of time from 3 to 80 minutes after detonation is given by the equation:

$$\bar{D} = 1.0 \times 10^5 t^{-1.7} \qquad (4.1)$$

Where: $\bar{D}$ = Average dose rate, r/hr.
t = Time after detonation, minutes.

This average dose rate, $\bar{D}$, may vary by as much as a factor of two for any given penetration.

Beyond 1 hour after detonation, when the mushroom begins to be dispersed by the winds, a more-rapid decay of the radiation dose rate in the cloud is noted in which the slope may be as great as -3 or -4.

The radiation dose rate in the stem beneath the mushroom of clouds from water-surface or air detonations is less by a factor of five to ten than in the mushroom itself.

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[redacted]

In clouds from detonations in which the fission yield is less than 100 percent of the total yield, the radiation dose rate is reduced by a factor proportional to the ratio of the fission yield to the total yield.

The accumulated radiation dose that one receives in transit through the cloud is a function of two primary factors: (1) the radiation dose rate in the cloud (related to time after detonation, to the ratio of the fission yield to the total yield, and to the portion of the cloud through which transit is made, i.e., stem or mushroom); and (2) the length of time spent within the cloud as determined by the speed of the aircraft and the horizontal dimension of the cloud at the altitude of penetration. The diameters of the stem and mushroom increase somewhat with greater yields.

Considering all these factors, two generalizations, substantiated by the penetrations actually flown, may be made: (1) with the tropopause at 55,000 feet, one may fly through the cloud from any yield for a 100-percent-fission weapon in a high-performance aircraft at an altitude of 45,000 feet at 20 minutes after detonation for an expected radiation dose of 25 r; (2) with the same height tropopause, one may fly through the cloud (stem) from any 100-percent-fission weapon at 30,000 feet as early as 10 minutes after detonation for a radiation dose of the same magnitude.

Moderate to severe bumpy turbulence was encountered in one of the clouds penetrated at times of 22 to 40 minutes after detonation. Slight to no turbulence was encountered in the other clouds penetrated during a similar time range. Turbulence was not a problem in any of these penetrations, and it was considered not likely to be a serious problem in a penetration as early as 10 minutes after detonation.

Icing was encountered in some of the penetrations, but caused no difficulty, except in the case of two aircraft penetrating a cloud from a water-surface detonation at the maximum altitude of 50,000 feet. This icing forced the pilots of these aircraft to reduce power on the jet engines in order to avoid overheating.

The contamination factor on the B-57B aircraft, as defined herein, averaged 0.6 ± 0.2 percent per minute in penetrations of clouds from air, land-surface, and water-surface detonations. This factor enables one to estimate that portion of the total dose received which is accrued during the flight back to base after exit from the radioactive cloud. In the penetrations made for this project, the return flight took about 50 minutes, and the come-home dose averaged about 15 percent of the total. On return flights of 2 to 3 hours duration in this aircraft the come-home dose would be no more than 25 percent of the total dose for early penetrations of the cloud.

4.2 RECOMMENDATIONS

There are no recommendations at this time.

REFERENCES

6. Landahl, H. D.; Calculations of the Hazard Involved in Passage through a Radioactive Cloud Resulting from a Nominal Atomic Bomb; Quarterly Progress Report No. 1, October 1951, USAF Radiation Laborato
University of Chicago, Chicago, Illinois; OFFICIAL USE ONLY.